ESTCP
Cost and Performance Report

(WP-200905)

Demonstrate a Low Biochemical Oxygen Demand Aircraft Deicing Fluid

June 2013

This document has been cleared for public release; Distribution Statement A

ENVIRONMENTAL SECURITY
TECHNOLOGY CERTIFICATION PROGRAM

U.S. Department of Defense

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **JUN 2013**	2. REPORT TYPE	3. DATES COVERED **00-00-2013 to 00-00-2013**

4. TITLE AND SUBTITLE **Demonstrate a Low Biochemical Oxygen Demand Aircraft Deicing Fluid**	5a. CONTRACT NUMBER
	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Environmental Security Technology Certification Program (ESTCP),4800 Mark Center Drive, Suite 17D08,Alexandria,VA,22350-3605**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S)
	11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT

Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**38**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

COST & PERFORMANCE REPORT
Project: WP-200905

TABLE OF CONTENTS

Page

This page left blank intentionally.

LIST OF FIGURES

Page

LIST OF TABLES

Page

ACRONYMS AND ABBREVIATIONS

ADF	aircraft deicing fluid
AFB	Air Force Base
AMCTES	Air Mobility Command Test and Evaluation Squadron
AMS	Aerospace Material Specification
ANG	Air National Guard
ASTM	ASTM International
BOD	biochemical oxygen demand
BRAC	Base Realignment and Closure
CFR	Code of Federal Regulations
COD	chemical oxygen demand
D^3	Degradable by Design Deicer™
DI	deionized
DoD	U.S. Department of Defense
EPA	U.S. Environmental Protection Agency
EPCRA	Emergency Planning and Community Right-To-Know Act
ESTCP	Environmental Security Technology Certification Program
JTP	Joint Test Protocol
LO	low observable
LOUT	lowest operational use temperature
mg/L	milligrams per liter
NPDES	National Pollutant Discharge Elimination System
NSPS	New Source Performance Standards
OA	operational assessment
OBE	overcome by events
PG	propylene glycol
PMC	polymer matrix composite
SAE	Society of Aerospace Engineers
SAIC	Science Applications International Corporation
SERDP	Strategic Environmental Research and Development Program
SME	subject matter expert
USAF	U.S. Air Force

This page left blank intentionally.

ACKNOWLEDGEMENTS

The following individuals and organizations contributed to the successful execution of this demonstration/validation project:

The project manager for the EcoFlo aircraft deicing fluid demonstration project was Ms. Mary Wyderski from the U.S. Air Force (USAF) Aeronautical Systems Center. In the early planning and coordination for this program, Ms. Wyderski was assisted by several government representatives, including Dr. Elizabeth Berman of the Air Force Research Laboratory, Mr. Benet Curtis and Mr. Michael Sanders of the Air Force Petroleum Agency, Mr. Thomas Lorman of the Air Force Aeronautical Systems Center, and Mr. Charles Ryerson of the Army Corps of Engineers Cold Regions Research and Engineering Laboratory. Mr. Donald Tarazano of Science Applications International Corporation (SAIC) and Mr. Alex Meyers of Clariant Corporation (formerly Octagon Process, LLC) also contributed to this effort.

Mr. Stephen Chicosky, MSgt John Florian, SMSgt Jason Hale, and the participants from the USAF Air Mobility Command Test and Evaluation Squadron and the 108^{th} Wing, New Jersey Air National Guard at Joint Base McGuire-Dix-Lakehurst provided critical support during the Operational Assessment (field demonstration) effort.

The materials compatibility effort was supported by Ms. Leanne Debias of Concurrent Technologies Corporation.

The wind tunnel fluid evaluation effort was supported by Ms. Arlene Beisswenger of the Anti-Icing Materials International Laboratory (AMIL) at the University of Quebec at Chicoutimi; Ms. Melissa Tolentino, Mr. Steven Chapel, Mr. Charles Royas, Mr. John Braun and Mr. Alan Lepper of The Boeing Company; and Ms. Megan Hawk and Mr. James Davila of SAIC.

Finally, the financial support of the Environmental Security Technology Certification Program (ESTCP) is hereby acknowledged.

This page left blank intentionally.

EXECUTIVE SUMMARY

Aircraft deicing fluids are required to remove frozen precipitation from aircraft prior to flight, ensuring mission capability in winter conditions. Without effective removal of frozen precipitation, lift and control might be compromised and safety of flight is jeopardized. A problem with conventional fluids in use today, however, is that the primary component is propylene glycol (PG), which can exhibit a high biochemical oxygen demand (BOD) in receiving waters when it degrades. Thus the waste fluid can either threaten aquatic life or impede the effectiveness of waste water treatment processes, depending on where runoff from airfield deicing operations is directed. Because of this, some newer deicing fluid formulations feature the reduction or elimination of PG to assuage the BOD impact and reduce related runoff handling and permitting costs.

The aim of this demonstration was to investigate whether one reduced PG aircraft deicing fluid, EcoFlo (and later EcoFlo II), was effective at deicing military aircraft while having no negative effects on flight performance, operational safety, and aircraft materials. EcoFlo and EcoFlo II have both been tested for compliance with Society of Aerospace Engineers (SAE) Aerospace Material Specification (AMS) 1424G, the commercial specification covering aircraft deicing fluids, and EcoFlo had been marketed for commercial aircraft use.

Prior to the demonstration involving deicing with EcoFlo on operational Air Force aircraft, two laboratory evaluations were performed. The first consisted of observing the compatibility of EcoFlo with materials likely to be found on military aircraft but not commercial aircraft (i.e., not covered by SAE AMS 1424G). For most of the materials tested, EcoFlo was shown to either have no impact or no impact more significant than that of the baseline fluid, which is a conventional PG fluid. A few cases were identified where EcoFlo did not perform as anticipated; these instances were marked for future evaluation should the fluid be considered for aircraft featuring those specific materials.

The second laboratory evaluation involved testing in a wind tunnel. Some previously reduced PG deicing fluids showed a tendency to leave a residue that both obscured visibility through windows or observation ports and left surfaces excessively slippery, hindering post flight inspection and maintenance. The project team determined that a wind tunnel evaluation might be suitable prior to investing the time and effort in a full aircraft demonstration. Surfaces exposed to the fluid were submitted to airflow consistent with takeoff velocities and then tested for impeded visibility and slipperiness. Although this evaluation was a simple approximation and could not duplicate the complex airflows encountered by various parts of an aircraft, it provided some indication that EcoFlo was likely to act similarly to conventional PG fluids and not leave a significant residue.

Prior to the full demonstration, the manufacturer of EcoFlo informed the project team that they were planning to market a new formulation, EcoFlo II (containing more PG, but still featuring a lower BOD than conventional PG fluids) and eventually discontinue EcoFlo. The project team considered the limited information available on the proprietary formulation and determined that it was unlikely that EcoFlo II would perform worse than EcoFlo in any of the laboratory evaluations already completed. Therefore, EcoFlo II was acquired for the full scale demonstration.

The full demonstration, using EcoFlo II, was carried out at Joint Base McGuire-Dix-Lakehurst on February 9, 2012. Maintenance personnel evaluated EcoFlo II for deicing effectiveness, including time, quantity of fluid, and labor required to thoroughly remove frozen precipitation on KC-135 aircraft. For comparison, a second aircraft was deiced with conventional PG fluid. A test flight crew checked for any inflight performance impacts attributable to the fluid, and then the maintenance crew performed post flight evaluations.

The experienced maintenance crew observed that the EcoFlo II effectively deiced the aircraft in an effective time frame and used a quantity of fluid typical for that type of aircraft with a given amount of frozen precipitation. However, because of rapidly changing weather conditions, a one-to-one, quantitative comparison to the conventional PG operation was inconclusive (the PG operation was likely aided by radiant heat when the skies cleared).

Flight characteristics were not impacted after the aircraft was deiced, although windows and viewing ports were obscured by fluid residue. Also, after the flight, aircraft surfaces were observed to be extremely slippery and a fall hazard for post flight inspection and maintenance. These factors led the onsite evaluation team to discontinue any further application of fluid (effectively ending the demonstration) and conclude that the EcoFlo II was not suitable for deicing on KC-135 aircraft.

EcoFlo II (as with EcoFlo) was formulated to reduce BOD impact while not affecting aircraft flight and maintenance operations (i.e., by not leaving any slippery, blurry residue). Unfortunately, EcoFlo II still showed these negative effects during this specific event. If this was an anomaly, the factors leading to this unexpected performance must be understood and controlled, otherwise the fluid must be reformulated to reliably prevent residue issues before implementation can be considered.

1.0 INTRODUCTION

1.1 BACKGROUND

Icy and snowy weather puts aircraft at risk as frozen contamination on aerodynamic surfaces can hinder lift and control. For the U.S. Air Force (USAF) to maintain an all-weather flying capability, it must maintain the ability to remove snow and ice from aircraft prior to take-off. This is currently accomplished by spraying a heated aircraft deicing fluid (ADF) on the surfaces, which melts, abrades and/or debonds the ice or snow.

Currently, ADF runoff can be a significant environmental problem at airports. The discharge of ADF into storm water management systems is subject to permitting and reporting requirements under the National Pollutant Discharge Elimination System (NPDES) program and the Emergency Planning and Community Right-To-Know Act (EPCRA). Also, run off new sources must consider New Source Performance Standards (NSPS) promulgated by the U.S. Environmental Protection Agency (EPA) under 40 Code of Federal Regulations (CFR) Part 449 in 2012. The U.S. Department of Defense (DoD) has made the reduction or elimination of the use of propylene glycol (PG) an environmental priority to help manage permitting under NPDES. Because each airfield is unique and storm water discharge permits are negotiated on a case-by-case basis by state environmental agencies, some bases face more stringent regulation than others.

The present ADF of choice by the USAF is PG, which has a relatively high biochemical oxygen demand (BOD) and chemical oxygen demand (COD) and can deplete oxygen levels in receiving waters and threaten oxygen dependent aquatic life. Also, high concentrations of deicing fluids are known to cause acute aquatic toxicological effects, due mainly to additives (e.g., to improve corrosion inhibition) and not the PG itself. Per Aerospace Material Specification (AMS) 1424G, Deicing/Anti-icing Fluid, Aircraft, Society of Aerospace Engineers (SAE) Type I (SAE, 2006), and the SAE G-12 Aircraft Ground Deicing Committee, in accordance with EPA permitting requirements, has established a toxicity limit of 4000 mg/L (at an ADF concentration that provides a -26°C freezing point) for all Type I (deicing type) fluids, regardless of the freezing point depressant (e.g., PG, ethylene glycol, and polyol based fluids).

A product developed by Battelle Memorial Institute using Strategic Environmental Research and Development Program (SERDP) funding exhibits the promise to be more environmentally friendly and cost effective than PG. The product was originally named Degradable by Design Deicer™ (D^3). The product failed field demonstrations due to visibility degradation [through aircraft windows] and slipperiness. The fluid was subsequently reformulated to eliminate these negative effects. It has been licensed to Octagon Process, LLC (Octagon Process has been purchased by Clariant Corporation) under the product name EcoFlo.

This program involved laboratory evaluations of an EcoFlo product followed by a field demonstration for ice removal and prevention of ice formation. The full demonstration was carried out on a KC-135 Aircraft supplied by the 108th Wing, New Jersey Air National Guard, located on Joint Base McGuire-Dix-Lakehurst.

1.2 OBJECTIVE OF THE DEMONSTRATION

The objective of the demonstration was to collect operational and performance data to demonstrate that the EcoFlo (and later, EcoFlo II) bio-based, reduced PG, Type I ADF is an acceptable replacement for the current conventional PG ADF. EcoFlo fluid will significantly reduce the utilization of PG and hazardous proprietary additive materials such as corrosion inhibitors.

Specifically, the test objectives were as follows:

1. Illustrate the effectiveness of the ADF as an operationally suitable deicing fluid. The fluid should have left insignificant residue, comparable to that of PG, and should have demonstrated equal or less visual degradation when compared to PG.
2. Identify any residual characteristics of the ADF during and following a successful operational flight after application of the fluid. The team inspected for residue remaining on the aircraft, leading edge dryness, fluid shearing and migration, and streaking.
3. Determine the operational benefits and/or potential issues associated with use of the ADF by a facility. The base observers and flight crews were asked: “Is there any noticeable difference in the handling of the aircraft? Is the material compatible with present spraying equipment and base deicing operations? Will Base Operations recommend use of the product?”
4. Determine cost benefits of adopting the alternative ADF. Additionally, using a previously developed template under Environmental Security Technology Certification Program (ESTCP) project WP-200409, determine the environmental cost impact on the base, if this fluid were accepted for use.
5. Evaluate compatibility with materials unique to military aircraft.

1.3 REGULATORY DRIVERS

ADF runoff is covered by NPDES authorized by the Clean Water Act. Additionally, new sources of ADF may be impacted by NSPS promulgated by the EPA under 40 CFR Part 449 in 2012.

2.0 TECHNOLOGY

2.1 TECHNOLOGY DESCRIPTION

A deicing fluid transfers heat to aircraft surfaces to either melt or soften frost, ice and snow, allowing it to run off the aircraft. The fluid is heated to approximately 180°F to increase the melting/de-bonding effectiveness. Also, pressurized application of the fluid provides mechanical force to abrade and dislodge frozen substances. It is critical that the fluid contributes to freezing point depression when mixed with the melted contamination so that nothing will refreeze on the aircraft. A picture of a typical deicing operation can be seen in Figure 1.

Figure 1. Typical deicing operation.

In addition to effectively removing frozen contamination, alternative deicing fluids should be similar to current conventional PG fluids so operations can progress without changing existing aircraft deicing equipment, and so that constituents do not harm hoses and seals. For DoD use, the fluid should also be compatible with unique military materials not addressed in commercial specifications.

The specific technologies evaluated, EcoFlo and EcoFlo II aircraft deicing fluids, are SAE AMS 1424 compliant alternatives to conventional PG fluids developed by Battelle and manufactured by Clariant Corporation. Both formulations of EcoFlo have a lower BOD and COD than conventional PG fluids. The fluid also exhibits reduced aquatic toxicity characteristics when compared to conventional PG fluids.

When this effort was initiated, only the EcoFlo formulation was being marketed by the manufacturer. Exact information on constituents and concentrations was considered proprietary and not shared, but characteristics and toxicity, as required for qualification to SAE AMS 1424, were available. The EcoFlo formulation was provided by the manufacturer for the material compatibility testing and the wind tunnel testing.

Subsequent to the laboratory testing, and prior to the aircraft demonstration, a new formulation called EcoFlo II was developed. Clariant Corporation informed the project team that they would likely discontinue EcoFlo in favor of EcoFlo II. Clariant provided no detailed information on the reformulation beyond stating that they reduced the volume fraction of glycerin relative to PG to reduce the viscosity and increase the freezing point at higher fluid concentrations.

Given budget and schedule constraints, the project team acknowledged that repeating laboratory testing for the new formulation would be unfeasible. The team considered that EcoFlo II had passed SAE AMS 1424 testing and, assuming fluid performance varied somewhat linearly with constituent quantities and that the concentration of PG was somewhere between that of EcoFlo and Octaflo EF (a conventional PG-based deicer), the performance should be no worse than that of the original EcoFlo. It was determined by EcoFlo project team subject matter experts (SME) that the reformulation would not significantly impact material compatibility properties and the demonstration moved forward with EcoFlo II.

2.2 ADVANTAGES AND LIMITATIONS OF THE TECHNOLOGY

EcoFlo and EcoFlo II are hybrid fluids that contain less PG than conventional PG-based deicing fluids (exact concentrations are considered proprietary by the manufacturer and not shared). The main advantages of EcoFlo and EcoFlo II, compared to existing PG-based ADF, include:

- Reduced oxygen demand for biodegradation,
- Reduced toxicity,
- Reduced odor associated with degradation,
- Anticipated lower life-cycle deicing costs,
- Reduction on the use of PG, and
- Reduction, through utilization, of a waste product that comes from bio-fuel production.

Limitations of EcoFlo and EcoFlo II include higher viscosity, reduced freezing point depression capabilities and higher surface tension than PG. These are not seen as major disadvantages, but do denote the physical chemistry differences between EcoFlo and pure PG. The most significant limitation for EcoFlo was that the lowest operational use temperature (LOUT) is -30.5°C compared to -33°C for PG. The EcoFlo II formulation is anticipated to have a LOUT closer to that of PG. Also, the higher surface tension and higher viscosity of EcoFlo did raise concerns over the ADF leaving residue on the aircraft after deicing operations but the EcoFlo II version claims a lower freezing point and lower viscosity.

3.0 PERFORMANCE OBJECTIVES

The goal of this evaluation was to determine if the new ADF performs as well as, or better than, PG-based deicing fluids. The demonstration included evaluation of the performance objectives captured below in Tables 1 and 2, with a discussion of key objectives following each table.

Table 1. Qualitative performance objectives.

Performance Objective	Data Requirements	Success Criteria	Results
Fluid is effective in removing snow and ice from aircraft.	Observations collected from personnel with experience in aircraft deicing operations: flight line personnel, deicing truck operator, flight crew, various DoD and contractor personnel. Observation/Data sheets will be collected for each deicing event.	Concurrence among stakeholders that fluid is effective.	Fluid did effectively remove frozen contamination. PASS
Fluid coats the aircraft surface in a smooth and consistent manner with no foam. Fluid has good wetting characteristics and exhibits no pitting (indicating an oil/water-like mix).	Observations collected from personnel with experience in aircraft deicing operations: flight line personnel, deicing truck operator, flight crew, various DoD and contractor personnel. Observation/Data sheets will be collected for each deicing event.	Does not form persistent foam on deiced surfaces, i.e., foam that does not rapidly collapse or causes the surface to have the appearance of snow or slush. ADF show good wetting without film breaks, crawling, or fish eyes.	Fluid was observed to exhibit some foaming, which dissipated rapidly. Fluid appeared to flow and wet the surface adequately. PASS
Fluid is substantially removed from the plane surface during takeoff and flight, in a manner similar to PG-based Type I deicing fluids.	Observations collected from personnel with experience in aircraft deicing operations: flight line personnel, deicing truck operator, flight crew, various DoD and contractor personnel. Flight crew visual inspection of surfaces for streaking of windows (from inside) and to ensure no degradation in visibility. Observation/Data sheets will be collected for each deicing event.	Post flight inspection shows surfaces to be substantially clear without large areas of ADF residue (esp. on the leading edge of the wings, in quiet areas and on windows).	Although fluid appeared to shear/flow from aircraft surfaces, post flight inspection indicated residue remained. FAIL
Fluid exhibits slipperiness comparable to or less than that of PG on the deicing pad.	Observations collected from field technician and government and contract observers on the flight line.	No significant increase in slipperiness when walking or sliding shoes on pavement.	Fluid was observed to lead to significant slipperiness. FAIL
Fluid has no impact on flight operations of the aircraft.	Observations collected from flight crew.	Flight control response, visibility, thrust (drag) and refueling boom operation are not compromised.	Fluid did cause visual degradation on some windows during flight. FAIL

Table 1. Qualitative performance objectives (continued).

Performance Objective	Data Requirements	Success Criteria	Results
Fluid requirements similar to PG.	Observations from experienced deicing operator.	Volume of fluid required for effective deicing is comparable or less than PG.	Changing weather conditions prevented comparative evaluation with PG. INCONCLUSIVE
Low slipperiness and visual degradation (wind tunnel test).	Measurement of fluid performance in wind tunnel testing.	Slipperiness comparable to PG. Visual side-by-side measurements comparable to PG.	No significant visual degradation, and slipperiness comparable to PG. PASS
General/overall performance of fluid.	Interviews of flight line operators, and flight crew.	Performance suitable for recommendation to Base Commander.	Demonstration participants concerned with residue issues. FAIL

Table 2. Quantitative performance objectives.

Performance Objective	Data Requirements	Success Criteria	Results
Fluid meets SAE AMS 1424G.	Laboratory Testing per specification.	Pass all 29 requirements under this specification.	PASS
Fluid passes material compatibility testing.	Test to the draft DoD Deicing JTP.	Successful results in compatibility JTP tests.	PASS
Measurable environmental benefits per deicing fluid decision support tool*.	Facility characteristics, fluid use and runoff measurements – all input into Deicing Fluid Decision Support Tool.	Positive environmental cost benefit results as indicated by Deicing Fluid Decision Support Tool.	Decision Support Tool not utilized due to fluid failure in demonstration. OBE

* The deicing fluid Decision Support Tool is a MS Excel based tool developed under a previous effort. It features numerous fields for entry of ADF chemistry, usage and permitting data and provides a calculation of cost benefits of alternative ADFs versus conventional PG fluids.

OBE = overcome by events
JTP = Joint Test Protocol

4.0 SITE/PLATFORM DESCRIPTION

4.1 TEST PLATFORM/FACILITIES

Initially, the field demonstration was planned for Bangor, Maine, with the cooperation of the Maine Air National Guard (ANG). One request of that organization was that the demonstration involve an experienced flight test crew to safely perform the inflight portion of the evaluation. This necessitated a request for an Operational Assessment and led to the involvement of the Air Mobility Command Test and Evaluation Squadron (AMCTES) in the demonstration.

As coordination for the demonstration progressed, it became apparent that the Maine ANG would not be able to support the event (due primarily to an unusually short winter deicing season combined with operational commitments for aircraft). AMCTES was able to work with the 108th Wing, New Jersey ANG at Joint Base McGuire-Dix-Lakehurst to undertake the demonstration.

Joint Base McGuire-Dix-Lakehurst was formed in October 2009, from McGuire Air Force Base (AFB), Fort Dix, and Naval Air Engineering Station Lakehurst as a result of the 2005 Base Realignment and Closure (BRAC). The base encompasses 42,000 acres. In addition to housing the 108th Wing, McGuire field is home to the 305th Air Mobility Wing, the 514th Air Mobility Wing and other mission partners.

The 108th Wing received its first KC-135 and began refueling missions in late 1991. The KC-135 Stratotanker has provided refueling and airlift for the USAF for over 50 years. The aircraft has a wingspan of over 130 feet and a fuselage length just over 136 feet. It can carry 200,000 pounds of fuel for transfer. The Air National Guard currently has 180 KC-135 aircraft in inventory.

4.2 PRESENT OPERATIONS

Many organizations and platforms operate out of Joint Base McGuire-Dix-Lakehurst. For the USAF, those occasionally requiring deicing services for the 108th, in addition to the 305th Air Mobility Wing, which operates KC-10s and C-17s. The base also hosts U.S. Navy C-130s and C-9s, and civilian airlines that also require deicing.

At Joint Base McGuire-Dix-Lakehurst, the last three deicing seasons (October 2009 to February 2012) have covered 4 to 6 months. During those combined seasons, the USAF issued 258,600 gallons of Type I ADF concentrate (subsequently diluted for use to an approximate 50/50 mix with water).

The facility enlists Inland Technologies International, LTD for collection and recycling of fluids. Spent fluid, diluted with any water, slush or snow removed from the aircraft or present on the flightline at the time of collection is collected and processed. During the last three deicing seasons, 105,531 gallons of fluid mix was collected, and it is estimated that 15-20% of this is glycol.

4.3 SITE-RELATED PERMITS AND REGULATIONS

No permits were required specifically for the demonstration and no local regulations impacted the demonstration. EcoFlo II differs from current conventional PG deicing fluids only in the reduction of PG and the inclusion of non-hazardous alternatives. The reduction in PG (resulting in a reduced BOD and COD) and the elimination of hazardous additives results in a product with no additional regulatory and permitting burden. The result is anticipated to be similar wherever EcoFlo II might be implemented.

5.0 TEST DESIGN

The approach to this demonstration/validation involved three parts. The first two parts consisted of laboratory scale testing, and are discussed below. The final part was the field demonstration on actual aircraft in winter deicing conditions as discussed in Section 5.2.

5.1 LABORATORY TESTING

Material compatibility testing was performed to ensure EcoFlo is suitable for contact with unique military aerospace materials. Although SAE G-12 Aircraft Ground Deicing Committee has established commercial standards to which the fluid is tested, the DoD utilizes materials beyond those typical in the commercial world, and testing beyond the commercial standard must be considered. Material compatibility was evaluated per the Draft Deicing JTP by Concurrent Technologies Corporation and is discussed in detail in the WP-200905 project Final Report.

In addition to material compatibility, EcoFlo was studied in wind tunnel testing. Through wind tunnel testing the team hoped to confirm EcoFlo contributed no risk for ADF residue complications, a factor that has impacted flight demonstrations with other non-PG ADF formulations. The investigation studied the condition of surfaces exposed to aircraft takeoff speed airflow in a wind tunnel subsequent to the application of EcoFlo or a conventional PG fluid. Transparent surfaces were evaluated for any impact on visual clarity attributable to ADF residue and painted aluminum surfaces were evaluated for slipperiness. The wind tunnel test report is discussed in detail in the project Final Report.

5.2 TECHNOLOGY DEMONSTRATION

The third part of the demonstration/validation was the application of the fluid on actual aircraft during winter deicing conditions. The field demonstration was performed as an Operational Assessment (OA) by AMCTES, utilizing KC-135 aircraft at Joint Base McGuire-Dix-Lakehurst, NJ.

AMCTES developed the assessment protocol based on the OA request and the demonstration plan, and with extensive coordination with the EcoFlo demonstration project team.

This page left blank intentionally.

6.0 PERFORMANCE ASSESSMENT

6.1 LABORATORY TESTING

6.1.1 Material Compatibility Testing

The first part of the EcoFlo evaluation, testing the fluid compatibility with common military materials, was performed by Concurrent Technologies Corporation.

The EcoFlo fluid performed well, with the exception of percent volume swell of elastomeric materials (note that the conventional PG control fluid, Octaflo EF, also did not perform well with several of the elastomeric materials) and volume swell of low observable (LO) sealant, but with uncertainty over adequate cure of the sealant. Results of the testing are summarized below in Table 3 and are discussed in the WP-200905 project Final Report.

Table 3. Material compatibility testing.

Material Category	Test Method	Result
Metallic Materials	Alternate Immersion	Pass
	Stress Corrosion Cracking	Pass
	Total Immersion Corrosion	Pass
	Effect on Unpainted Surfaces	Pass
PMC Material	In-plane Shear	Pass
	Barcol Hardness	Pass
	Glass Transition Temp	Inconclusive
	Sandwich Corrosion	Pass
	Thermal Oxidative Stability	Pass
	Percent Weight Gain	Pass
Elastomeric Materials	UTS/Percent Elongation	Pass
	100% and 300% Modulus	Pass
	Peel Strength/% Cohesive Failure	Pass
	Shore A Hardness	Pass
	Percent Volume Swell	Fail
Aircraft Wire Insulation	Immersion/Bend	Pass
	Voltage Withstand	Pass
Carbon-carbon Brake	Oxidation Resistance	Comparable to control
Infrared Windows	Change in Transmission	Pass
LO Coatings	Liquid Uptake	Pass
	Adhesion	Pass (Some inclusive results – conspicuous failures for both control and EcoFlo)
	Pencil Hardness	Pass (Some inclusive results – conspicuous failures for both control and EcoFlo)
LO Sealant	Volume Swell	Fail – potential cure issue
Lubricants and Greases	Humidity	Pass
	Torque Rheometry	Pass
Cannon Plugs	Insulation Resistance	Unmated only – some failures
	Voltage Withstand Testing	Unmated only – some failures
Plastic Windows	Crazing Effect	Pass

PMC = polymer matrix composite

The testing did result in a few inclusive results and failures. For PMC materials, the determination of glass transition temperature and how it is impacted by the ADF was inconclusive as the differential scanning calorimeter provided an indication of melting temperature, but not glass transition temperature.

For LO coatings, there were also some inconclusive results in adhesion and hardness testing. In adhesion testing, one coating stack-up failed the cross-hatch adhesion test (ASTM International [ASTM] D 3359, Method B) whether or not exposed (both passed the X-scribe adhesion test, ASTM D 3359, Method A). For pencil hardness testing, two coating stack-ups indicated a significant loss in hardness when measurements were performed before and after exposure to either the ADF or deionized (DI) water. Both of these instances indicate potential issues with test panel preparation rather than a failure attributable to EcoFlo.

EcoFlo did appear to be absorbed by LO sealants as the volume of all samples increased, including one sample which increased by over 200%, after exposure to the ADF. If LO sealant compatibility is considered critical on a specific aircraft, these results would indicate the need for further evaluation prior to utilizing the fluid.

Similarly, testing indicated possible compatibility issues with electrical cannon plugs. On at least some of the evaluations for both the Insulation Resistance and Voltage Withstand testing results indicate that EcoFlo might either damage the insulation within the cannon plug, or leave some conductive contamination compromising insulated components.

The materials compatibility testing was not a formal pass/fail screening of the test ADF prior to a full scale demonstration. To be acceptable for use, even by military organizations, the critical qualification is compliance with SAE AMS 1424. The material compatibility JTP is significant as it covers evaluation of materials that may be present on military aircraft and are beyond those evaluated under the AMS document, but it does not convey or restrict authorization to use the fluid. For this project, failure of an ADF to demonstrate compatibility with some of the tested materials was considered more of an issue for attention and future detailed evaluation than a cause to preclude the demonstration.

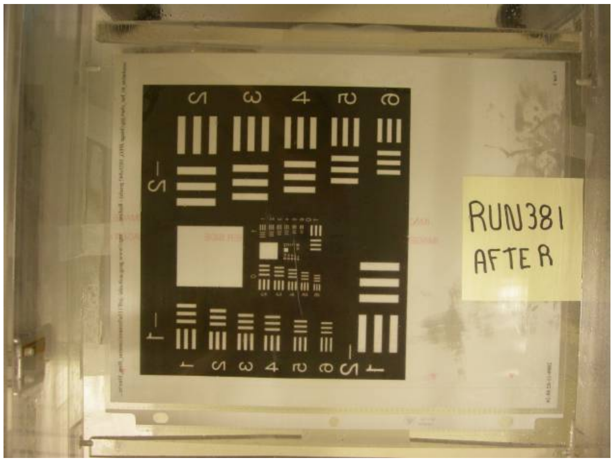
6.1.2 Wind Tunnel Testing

In the wind tunnel testing, surfaces (painted aluminum panels or the transparent bottom of the wind tunnel test section) were coated with either EcoFlo or a conventional PG fluid (Octaflo EF). Both fluids were initially diluted with water to form a 65% ADF/35% water (by volume) mixture. For some test runs, the fluid was then heated to reduce water content and approximate water loss due to spraying the heated fluid in actual operational use. The fluid was then applied in the controlled wind tunnel environment of either 0°C or minus -20°C. The wind tunnel was operated with an airflow of 65 m/s ± 5 m/s in the test section (the wind velocity called out in SAE Aerospace Standard 5900 for the High Speed Ramp test, based on takeoff conditions typical of large transport type jet aircraft).

To evaluate and document any degradation in clarity due to fluid residue on the test duct floor, the test duct section was opened and a photograph was taken showing the eye chart through the

Plexiglass floor. Visual clarity or resolution was evaluated for each set of test conditions in order to compare any degradation effects of the EcoFlo fluid with the PG fluid.

Results indicated that for all test conditions there was no notable impact on visual clarity for either the EcoFlo or the conventional PG ADF. A typical result is shown in Figure 2 below. It should be noted that, as this surface was parallel to the airflow, it is not a completely accurate approximation of the complex airflow around an aircraft and it cannot guarantee that excess fluid residue will not gather on some aircraft windows or observation ports. It does, however, show that in this approximation EcoFlo did not impact visual clarity any more than the PG ADF.



Wind Tunnel Temperature: 0°C
H_2O Reduction before Test; 0%
Initial Fluid Thickness: 1 mm
Wind Tunnel Run Time: 10 minutes

Figure 2. ADF wind tunnel visual clarity test configuration (EcoFlo ADF).

Measuring slipperiness was a difficult endeavor, as the interactions of surface profile, fluid properties, and dynamic factors of movement and impact are significantly complex. For this evaluation, a piston operated slip meter was utilized on the aluminum panels to determine contact angles at which a slip is likely to occur. The apparatus was adjusted so that a polymer test foot is extended toward the surface at a desired velocity and angle. The test foot is mounted on a hinged fixture so it can slide along the surface after impact if a slip occurs, thus simulating a foot stepping onto a wet surface and possibly losing traction. The actual measurement was determined by repeatedly adjusting the angle of impact until the test foot slipped. With this device, as the measured angle approaches a normal to the surface, the surface is considered more slippery. The measuring device itself affects the conditions at the point of impact, so it must be moved for each subsequent measurement, and during that time, evaporation and temperature changes may be influencing the fluid properties. It requires many repetitions of the test to attain statistically reliable and significant results, and the observations available in this brief evaluation were, at best, approximations.

Both fluids did consistently leave significantly slippery surfaces after wind tunnel exposure. In some cases, but not all, the EcoFlo appears to be slightly more slippery then the conventional PG ADF, but in all cases, the surfaces were well beyond the threshold of what might be considered a

safe walking surface (i.e., were unsafe surfaces). The evaluation results suggest that EcoFlo is comparable to conventional PG ADF with respect to residue concerns.

The project team understood that the evaluation limitations could not assuage all risk and that the fluid would show performance discrepancies during the full, on-aircraft demonstration. However the project team felt that this best effort at prescreening the fluid would at least reduce the risk significantly and that the full demonstration should proceed.

The wind tunnel evaluation is discussed in detail in the WP-200905 project Final Report.

6.2 TECHNOLOGY DEMONSTRATION

The demonstration was accomplished through an OA Request from Headquarters Air Force Materiel Command and was conducted by the AMCTES with the support of the 108^{th} Wing, New Jersey ANG at Joint Base McGuire-Dix-Lakehurst.

The extensive coordination activities required for the demonstration pushed the schedule into the first few months of 2012, at which time an unusually mild winter was making deicing opportunities scarce. The EcoFlo demonstration team determined that AMCTES would perform the evaluation at the earliest opportunity, even if those team members not local to the base would not have time to travel and observe the event. If the opportunity presented itself, a second round of testing would be performed with more advance notification. AMCTES and the 108^{th} Wing performed the demonstration on February 9, 2012.

AMCTES structured the evaluation with two assessment objectives: 1) whether the fluid is potentially effective for use on a KC-135 aircraft, and 2) whether it is potentially suitable for use on a KC-135 aircraft. The first objective was judged by the time and quantity of fluid required to deice the aircraft, with a target being no greater time or fluid than needed for deicing with conventional PG fluids. The second objective was broken down into compatibility with the aircraft (whether the fluid flowed or sheared off surfaces and whether it obscured windows or viewing ports), compatibility with deicing equipment, and impact to safety as judged by test participants.

Weather conditions hindered an objective comparison between deicing effectiveness of the EcoFlo ADF and a conventional PG ADF. The skies transitioned from overcast to sunny prior to deicing the aircraft with PG fluid, allowing more radiant heating of aircraft surfaces and likely resulting in quicker removal of frozen contamination with less ADF. The performance relative to the criteria of equal or less time for deicing using equal or less fluid was rated as inconclusive, but deicing operators estimated that time and EcoFlo II required was consistent with their previous experience with that type of aircraft and frozen contamination. The EcoFlo II was rated as satisfactory for the first assessment objective, and thus potentially effective for use on KC-135 aircraft.

EcoFlo II ran into difficulties against the second assessment objective, suitability for use on the aircraft. The fluid was rated as satisfactory in appearing to shear/flow from aircraft surfaces and in maintenance test participants' rating of compatibility with aircraft surfaces, but unsatisfactory in aircraft window/viewing port visibility after ADF application. Also, although the fluid did

appear to easily flow or shear from the aircraft, post flight inspection evinced a glossy appearance not seen on the conventional PG deiced aircraft.

The fluid was formulated to be compatible with all current deicing equipment, and the maintenance test team agreed by rating performance in that area as satisfactory.

With respect to safety concerns, maintenance test participants expressed concerns with the glossy, slippery residue remaining on the aircraft after flight. The increased slipperiness could be a potential fall hazard when performing servicing or aircraft inspections. For the safety of use criteria, the fluid performance was rated unsatisfactory and the EcoFlo II was determined to not be potentially suitable for use on a KC-135 aircraft.

Upon considering issues with window/viewing port visibility and safety concerns, AMCTES decided to perform no further demonstration activities with the current EcoFlo II formulation. The residue issues, something not new with non-PG or reduced PG ADF formulations, must be resolved before the Air Force would consider further evaluation of the fluid.

Complete details of the demonstration are documented in the Final Report, KC-135 Compatibility with Low Biochemical Oxygen Demand Deicing Fluid, Operational Assessment (AMCTES, 2012).

This page left blank intentionally.

7.0 COST ASSESSMENT

With the EcoFlo II ADF not performing in critical areas of the evaluation and the OA cut short, the collection of comprehensive data to support a detailed analysis of environmental cost factors was not completed. For a rough cost comparison, qualitative factors such as the cost of EcoFlo II or waste water handling at Joint Base McGuire-Dix-Lakehurst might be considered.

EcoFlo II is formulated to be a drop in replacement for conventional PG ADFs. There should be no changes required for equipment or operational procedures. During the demonstration, a one-to-one comparison between EcoFlo II and PG was inconclusive, due to rapidly changing weather conditions (i.e., the frozen contamination was not as heavy during the PG operation), but operators did not notice any significant or conspicuous ineffectiveness in deicing when applying the EcoFlo II. This would indicate that in general, implementation costs would be negligible.

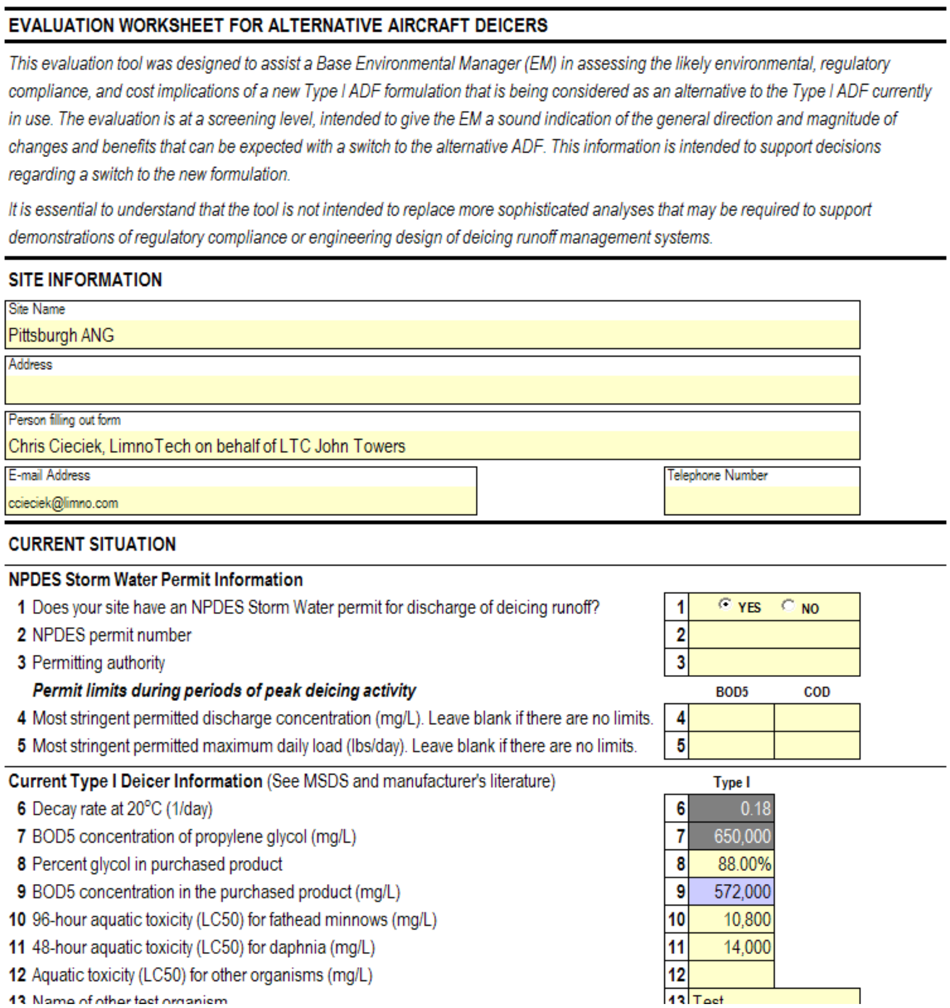
For raw materials, with EcoFlo II containing an increased quantity of PG, the cost could be anticipated to remain similar to that of a conventional PG ADF. Additionally, the manufacturer has indicated an intention to price EcoFlo II similarly to their conventional PG fluids.

Environmentally related costs may be more complicated to determine. EcoFlo could be expected to lower permitting costs and liability risks, as the BOD and COD are less than that of PG. At Joint Base McGuire-Dix-Lakehurst, however, waste PG is currently collected with a vacuum truck and recycled. Factors such as the market demand for recycled PG and the ability to recycle EcoFlo II would need to be considered in calculating the cost comparison between handling PG waste and handling EcoFlo II waste. Conceivably, a high demand for PG combined with any difficulty in recycling EcoFlo II could result in higher costs when handling the EcoFlo II waste.

An additional cost factor to consider would be the investment in demonstrating an alternative ADF. As this project illustrates, attempts to investigate fluid and residue behavior on aircraft surfaces (i.e., visibility degradation and slipperiness), are still unreliable. The pre-demonstration wind tunnel testing did not reveal a high risk for residue issues and indicated that EcoFlo could be anticipated to perform similarly to PG. The KC-135 demonstration showed residue was still a problem. Development of a more reliable, laboratory scale methodology for predicting alternate ADF behavior might help reduce the investment cost by adding certainty prior to coordinating and executing a full field demonstration with pre- and post-flight evaluations.

7.1 COST MODEL

The project team anticipated use of a deicing fluid Decision Support Tool, developed under a previous ADF demonstration, to analyze costs factors and determine the potential cost benefits resulting from implementation of EcoFlo II. A sample of some of the data to be collected in the tool is included in Figure 3. As discussed in Section 7.2, ultimately this tool was not used.



EVALUATION WORKSHEET FOR ALTERNATIVE AIRCRAFT DEICERS

This evaluation tool was designed to assist a Base Environmental Manager (EM) in assessing the likely environmental, regulatory compliance, and cost implications of a new Type I ADF formulation that is being considered as an alternative to the Type I ADF currently in use. The evaluation is at a screening level, intended to give the EM a sound indication of the general direction and magnitude of changes and benefits that can be expected with a switch to the alternative ADF. This information is intended to support decisions regarding a switch to the new formulation.

It is essential to understand that the tool is not intended to replace more sophisticated analyses that may be required to support demonstrations of regulatory compliance or engineering design of deicing runoff management systems.

SITE INFORMATION

Site Name: Pittsburgh ANG

Address:

Person filling out form: Chris Ciecieck, LimnoTech on behalf of LTC John Towers

E-mail Address: cciecieck@limno.com

Telephone Number:

CURRENT SITUATION

NPDES Storm Water Permit Information

1	Does your site have an NPDES Storm Water permit for discharge of deicing runoff?	**1**	YES	NO
2	NPDES permit number	**2**		
3	Permitting authority	**3**		
	Permit limits during periods of peak deicing activity		**BOD5**	**COD**
4	Most stringent permitted discharge concentration (mg/L). Leave blank if there are no limits.	**4**		
5	Most stringent permitted maximum daily load (lbs/day). Leave blank if there are no limits.	**5**		

Current Type I Deicer Information (See MSDS and manufacturer's literature)

			Type I
6	Decay rate at 20°C (1/day)	**6**	0.18
7	BOD5 concentration of propylene glycol (mg/L)	**7**	650,000
8	Percent glycol in purchased product	**8**	88.00%
9	BOD5 concentration in the purchased product (mg/L)	**9**	572,000
10	96-hour aquatic toxicity (LC50) for fathead minnows (mg/L)	**10**	10,800
11	48-hour aquatic toxicity (LC50) for daphnia (mg/L)	**11**	14,000
12	Aquatic toxicity (LC50) for other organisms (mg/L)	**12**	
13	Name of other test organism	**13**	Test

Figure 3. Decision support tool example.

7.2 COST ANALYSIS AND COMPARISON

Due to the scarcity of icing weather and resulting short notice for the initial demonstration, non-local team members were not able to travel to Joint Base McGuire-Dix-Lakehurst and collect data to utilize the tool. Effectively, once it was determined that the fluid raised some safety concerns, and the demonstration would not be repeated, the team acknowledged that there would no longer be significant value in attempting to visit Joint Base McGuire-Dix-Lakehurst to attempt to collect or estimate this data.

As a drop in ADF replacement, EcoFlo (or EcoFlo II) should have little direct cost impact on current deicing operations. The product was formulated for comparable performance with the same application requirements and equipment used for conventional PG fluids. Cost benefits were anticipated through factors resulting from the waste or used fluid once deicing operations are complete. Current cost elements include monitoring and/or permitting associated with handling of fluid runoff and control procedures or infrastructure such as collection for recycling or storm drain plugs and retention ponds. Unfortunately, benefits related to these cost elements

are diminished as the strategy to reduce persistent fluid residue issues has been to add additional PG to the alternative ADF formulations. Increasing PG concentration in subsequent formulations gradually erodes the reduction monitoring, permitting, and waste handling facility and operations costs potentially gained by the elimination of PG.

This page left blank intentionally.

8.0 IMPLEMENTATION ISSUES

As an SAE AMS 1424 Type I certified deicing fluid, compatible with current deicing equipment, EcoFlo II is designed to be a drop in replacement for conventional PG ADFs and should have no significant implementation issues.

The evaluation of compatibility with military materials did indicate a few areas of concern, and it would be recommended that those undergo further evaluation prior to application to aircraft utilizing those materials. Risk of exposure and degree of potential damage or degradation to the material should be analyzed and understood.

The primary impediment to implementation is the apparent residue that can obscure window/viewing ports and leave aircraft surfaces excessively slippery, causing safety concerns during post flight inspection and maintenance. This is not a new concern, and in this project it prompted the incorporation of a wind tunnel test to hopefully identify that characteristic prior to the full scale demonstration. Considerations of alternative ADFs for future implementation should research mechanisms causing this undesired performance trait and effective small scale or laboratory procedures to ensure it has been controlled or eliminated, before expending the time and cost on a full demonstration.

This page left blank intentionally.

9.0 REFERENCES

AMC Test and Evaluation Squadron. AMC Test 10-001-12, KC-135 Compatibility with Low Biochemical Oxygen Demand Deicing Fluid, Operational Assessment, Final Report. June 2012.
(Available from HQ AMC/TE, 402 Scott Drive, Unit 1A5, Scott AFB IL 62225-5364)

Society of Aerospace Engineers International. AMS 1424G, Deicing/Anti-Icing Fluid, Aircraft, SAE Type I. 18 January 2006.
(Available from SAE International, website: standards.sae.org/ams1424g)

This page left blank intentionally.

APPENDIX A

POINTS OF CONTACT

Point of Contact	Organization	Phone E-Mail	Role In Project
Ms. Mary Wyderski	AF/ASC/WWME WPAFB, OH	Phone: 937-656-5570 E-mail: Mary.wyderski@wpafb.af.mil	Principal Investigator
Dr. Elizabeth Berman	AF/AFRL/RXSC	Phone: 937-656-5700 E-mail: Elizabeth.berman@wpafb.af.mil	Materials SME Compatibility with DoD materials
Mr. Michael Sanders	AFPA/PTPT	Phone: 937-255-8107 E-mail: Michael.sanders@wpafb.af.mil	ADF SME Observe aircraft deicing operations
Mr. Stephen Chicosky	HQ AMC/TEAS	Phone: 618-229-2044 E-mail: Stephen.chicosky@us.af.mil	Test Manager
MSgt John Florian	AMC TES/TEL	Phone: 609-754-1690 E-mail: John.florian@us.af.mil	Test Director
SMSgt Jason Hale	AMC TES/TEL	Phone: 618-229-1753 E-mail: Jason.hale@us.af.mil	Test Director
Mr. David Gipson	HQ AMC/A4/A4MYD	Phone: 618-779-2016 E-mail: David.gipson.2@us.af.mil	Functional Manager
CMSgt Michelle Evans	108th Wing/AMXS	Phone: 618-229-4981 E-mail: Michelle.evans@us.af.mil	Project Officer
Mr. Alex Meyers	Clariant Corporation	Phone: 201-417-2420 E-mail: alex.meyers@clariant.com	EcoFlo Manufacturer Representative
Mr. Thomas Lorman	AF/ASC/WNVV WPAFB, OH	Phone: 937-255-3530 E-mail: Thomas.lorman@wpafb.af.mil	ESOH SME
Mr. James Davila	SAIC	Phone: 937-219-7616 E-mail: james.a.davila@saic.com	SAIC Project Lead
Dr. Charles Ryerson	Army/CRREL Hanover, NH	Phone: 603-646-4487 E-mail: Charles.c.ryerson@usace.army.mil	Provide insight in applicability to Army applications

This page left blank intentionally.

ESTCP Office
4800 Mark Center Drive
Suite 17D08
Alexandria, VA 22350-3605
(571) 372-6565 (Phone)
E-mail: estcp@estcp.org
www.serdp-estcp.org